Development of an Ejectable Cubesat Onboard a Sounding Rocket

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Technische Universität Berlin is researching fluid dynamic actuation technology as a new means of attitude control for small satellites. Meanwhile, the Rocket and Balloon Experiments for University Students (REXUS/BEXUS) is an opportunity to realize a close simulation of a real space mission from start to finish. Student's from Technische Universität Berlin's Chair of Space Technology are currently developing the Technische Universität Berlin Pico-satellite Experiment-6 (TUPEX-6) within the framework of the REXUS/BEXUS program. TUPEX-6's goals are to experimentally demonstrate the utility of fluid dynamic actuators while simultaneously providing students a unique hands-on opportunity to design, build, test, and fly a small spacecraft. The mission is set to launch on-board the REXUS 25/26 mission in March of 2019, and will provide approximately 120 seconds in milligravity for the experiment to take place.

Keywords—CubeSat; technology demonstration; attitude control; sounding rocket

I. INTRODUCTION

Modern-day CubeSats rely on magnetorquers, a system of reaction wheels, or a combination of the two for active attitude control. Magnetorquers are cost-effective and robust; however, they are slow and coarse in their pointing ability. Conversely, reaction wheels allow for agile and accurate pointing. Additionally, reaction wheels tend to occupy volume within the spacecraft that could otherwise be allocated to larger payloads, which would expand the mission capabilities of CubeSats.

Pico-satellite fluid-dynamic actuators (pFDAs) are a novel means of attitude control for pico-satellites [1]. These actuators are being developed at Technische Universität Berlin (TU Berlin) with the goal to combine precise attitude control and low cost, while increasing the integration density. The student project Technische Universität Berlin Pico-satellite Experiment-6 (TUPEX-6) aims to demonstrate the pFDA technology in space. Through participation in the Rocket and Balloon Experiment for University Students (REXUS/BEXUS) program TUPEX-6 has the possibility to launch the experiment into milligravity. An attitude control system consisting of pFDAs is being incorporated into a free falling unit (FFU). A REXUS experiment module with a CubeSat ejector mounted inside is called the rocket-borne equipment (RBE). The FFU is deployed by the ejector to conduct the experiment in milligravity.

Since TUPEX-6 is a student project, it serves as an educational opportunity for the participating students. Except for the designated payload, the pFDA attitude control system, the system is being developed by the TUPEX-6 team. The FFU is closely resembling a single unit (1U) CubeSat, with most of the vital subsystems. Due to the fact that it ejects a pseudo-CubeSat, the RBE is designed complying with the CubeSat design specifications (CDS)[2]. A ground station is being developed by the team as well. Assistance in development is provided by the Chair of Space Technology at TU Berlin and Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation (ZARM).

II. REXUS CAMPAIGN

The REXUS/BEXUS program is realized under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through the collaboration with the European Space Agency (ESA). Experts from DLR, Swedish Space Corporation, ZARM and ESA provide technical support to the student teams throughout the project. EuroLaunch, the cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Two rockets and two balloons are launched from Esrange per year with a total of about 20 students designed and built experiments.

TUPEX-6 has been selected for the REXUS 26 mission, with a launch target of March 2019. The REXUS rocket is an unguided, spin stabilized, single stage rocket capable of achieving 90 km altitude for 40 kg of experimental payloads. REXUS/BEXUS is the ideal program for TUPEX-6 versus alternate gravity reducing programs including parabolic flights or drop towers. While parabolic flights offer a lot of total time in microgravity, individually experiments are limited to 20 to 30 seconds. This problem is the same for drop tower experiments with the additional issue of a confined experimental compartment.

The REXUS/BEXUS program is a unique opportunity for students to gain comprehensive hands-on experience progressing a mission through all phases of a space project. Going beyond design phases, typical of master's level coursework, students get to order and build hardware. Additionally, they get to qualify their concepts for rocket flight, before integrating the experiment into REXUS's experiment module, and ultimately the rocket. Finally, student's experience a launch campaign and determine design and performance success after landing. Throughout the program, reviews are conducted with the REXUS/BEXUS program managers. The program is a great situation to educate masters level students in a practical manner which represents the ESA and ECSS frameworks as well as an avenue to trial a new system in attitude control technology. TUPEX-6 has recently progressed to mission phase C, having passed the preliminary design review at the Esrange Space Center, Sweden with agencies organizing REXUS/BEXUS in February 2018. The team is now working towards the critical design review, which will take place in June 2018.

III. TEAM

Project work is a collaborative effort by students from various areas of study at TU Berlin. However, the majority of students on the team are from the German Master of Aerospace Engineering and International Master of Space Engineering programs under the Chair of Space Technology within the Department of Aeronautics and Astronautics at TU Berlin. A team of at least two students is responsible for each subsystem of the FFU and RBE. The TUPEX-6 project has become part of the Space System Design Project course within the International program, and the German Raumfahrt-systementwurf lecture. The entire project is managed by a core team of nine students with a couple of senior members from the Department acting as advisors. Overall the team is composed of 40 students from 8 countries including Germany, India, Indonesia, Ireland, Mexico, South Africa, South Korea, and the United States. They have diverse backgrounds and experience in aerospace, electrical, and mechanical engineering as well as computer science and physics. This cooperation provides close inter-cultural exchange on technical and personal levels for students. In addition to the experience REXUS/BEXUS provides, TUPEX-6 has become an excellent vehicle for students to interact with researchers from the Department to draw on knowledge from prior and other current projects.

IV. PICO SATELLITE FLUID DYNAMIC ACTUATORS

Fluid-dynamic actuators (FDAs) control the attitude of a spacecraft by conservation of angular momentum [3]. Developed for nano-satellites, a single, circular FDA is currently flying on the TU Berlin satellite TechnoSat[4]. Scaled down to a CubeSat form factor, pFDAs are the designated payload of TUPEX-6. A pFDA consists of liquid metal, flowing inside a 3D-printed closed loop channel. Figure 1 illustrates the basic configuration of a fluid-dynamic actuator. The motion of the fluid is controlled by an electromagnetic pump. The actuators do not include any mechanical moving parts and are therefore believed to be wear free. By changing the flow rate of the liquid, torque is induced about its vector of angular momentum. The attitude and magnitude of the vector of angular momentum is dependent on channel geometry. It

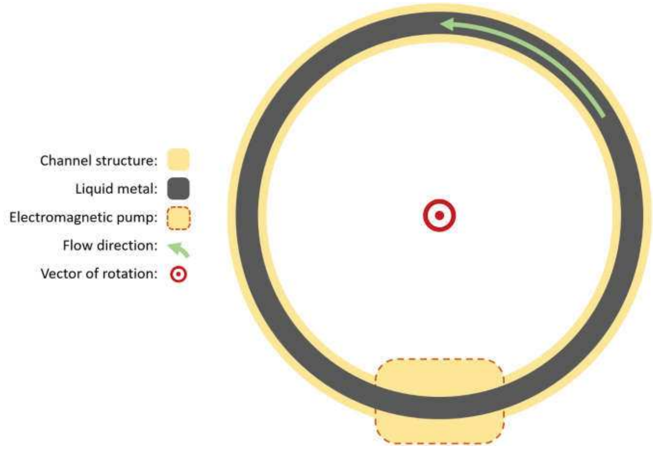

Figure 1: Fundamental configuration of a fluid-dynamic actuator

coincides with the vector of rotation and the main principal axis of the fluid in the channel [5].

Previously, a prototype has been developed and tested. Designed to be integrated in the side panel of a 1U CubeSat, pFDA-A2 has a square shape. Three pFDAs integrated in a 90° angle to each other are necessary for attitude control about all three axis. To achieve 3-axis redundancy, six actuators would be required.

Further research on pFDA technology, with the goal to develop a redundant attitude control system using four actuators, has already been conducted. This research resulted in an L-shaped pFDA. As previously described, the vector of rotation resides along the main principal axis of the moving fluid. For L-shaped pFDAs this principal axis lies in the remaining symmetry plane. Figure 2 shows a mechanical model of a L-shaped pFDA with its remaining symmetry plan and vector of rotation.

Using four L-shape actuators, a redundant 3-axis attitude control system can be constructed. The pFDAs are configured so that the four vectors of rotation are in a tetrahedral configuration. This configuration is often used in reaction wheel systems, since it allows for the highest angular momentum capacity [7]. A attitude control system consisting of four L-shape pFDAs in tetrahedral configuration is designated as the payload of TUPEX-6.

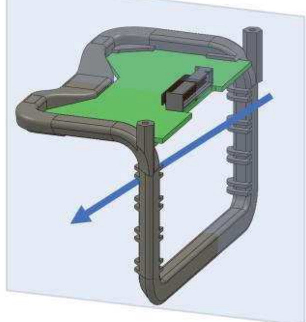

Figure 2. L-shape pFDA with remaining symmetry plane and vector of angular momentum [6]

Figure 3. Preliminary mechanical model of free falling unit [6]

V. Free Falling Unit

A free falling unit is being developed within a mechanical structure very close to the 1U CubeSat form factor to house and support TUPEX-6's experimental payload, the four pFDAs. To increase the integration density, additional structure on the actuator channels was designed to hold printed circuit boards. The subsystems necessary to carry out the experiment, store, and transmit data will be built on these boards. The on-board subsystems are reflective of those necessary to a typical orbital Cubesat mission, however their complexity has been reduced to meet the time and budgetary restraints of the project. The pFDAs will serve as the attitude control system, but will work in parallel with an attitude determination system. The payload data handling unit and on-board computer will share a microprocessor while storing data on redundant SD cards. A communications unit will live stream data to the RBE throughout the experiment. The entire FFU will run on an electrical power system with batteries, but no solar cells. Figure 3 is a model of the FFU within a 1U CubeSat structure.

The recovery unit is colored red in the model, which will house and deploy a parachute for landing as well as provide GPS coordinates for search and recovery. This volume is made available by the pFDAs. The actuators' integrability creates space for potential payloads of the future that may otherwise be allocated to more traditional attitude control systems.

VI. Rocket Borne Equipment

The TUPEX-6 rocket-bore equipment is being hosted by an experiment module located in the upper half of the REXUS rocket. The RBE consists of an ejector for the FFU and the necessary electronics. The experiment module is provided by ZARM and modified to allow deployment of the pseudo-CubeSat. As the FFU complies with the CDS, the ejector does as well. The ejector features a container, in which the FFU is stored prior to ejection. The pseudo-CubeSat is held in place by an in-flight actuated hatch, which closes the container until it is released. A metal string is holding the

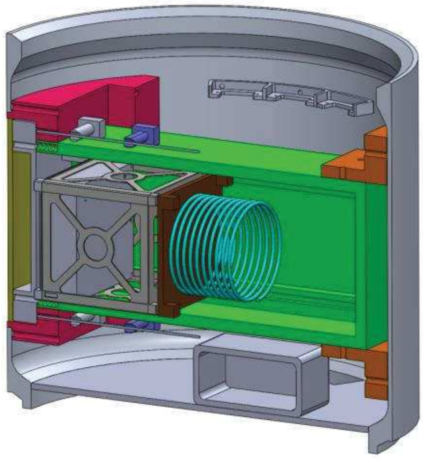

Figure 4. Cut away of mechanical model of RBE with experiment module, ejector and FFU [8]

hatch in place and is released using pyro cutters. Further the ejector hosts a spring with a push plate to perform the ejection. The push plate features an electrical interface between the REXUS rocket and the FFU. This interface allows for recharging of the FFUs' batteries, as well as booting prior to ejection. The ejection is designed to be a single mechanism, so by releasing the hatch, the pseudo-CubeSat is ejected by the spring.

Figure 4 shows a cut away of the preliminary model of the RBE. Visible are the hatch (yellow), the container (green), the spring (blue) with the push plate (brown). Furthermore, the REXUS experiment module, a FFU primary structure and a box containing any electronics (grey) are shown.

VII. Experiment

The experiment is a sequence of two phases performed autonomously by the free falling unit during its flight in milligravity, following ejection from REXUS and the RBE. It utilizes the 3-axis redundant pFDA attitude control system to demonstrate changes in its attitude. Using an array of sensors, the FFUs' attitude will be determined while in flight. The experiment will demonstrate the capabilities of pFDAs, as well as the redundant architecture of the system. After being launched to approximately 80km altitude, the FFU is being ejected, to conduct the experiment in milligravity, before reentering the denser atmosphere.

The first phase of the experiment utilizes only the actuator, by rotation about its main principal axis. This is done to demonstrate the capabilities of pFDAs. The second simulates the in-flight failure of one actuator. Therefore, during this phase, rotation about the same axis as in the preceding phase is demonstrated utilizing all pFDAs but the previously used one. This part of the experiment shows the 3-axis redundancy of the pFDA attitude control system. The system allows for attitude control about all three axis, even in case of failure of one actuator.

VIII. CONCLUSION

Attitude control technology currently available to small satellites, namely CubeSats, is becoming increasingly insufficient at a proper balance of volume consumption and cost versus operational payload support. TU Berlin is researching a new technology, fluid-dynamic actuation, and simultaneously attempting to scale it for pico and nano satellite form factors. TUPEX-6 is a mission to experimentally verify the utility of these pico actuators via the REXUS/BEXUS program. The nature of the mission necessitates students to develop every element of a typical space mission including, a free falling unit carrying the payload, RBE to support and eject the FFU, a ground station to receive data, and mechanical and electrical ground support equipment. As a result, the project is a superior educational experience for the students by very closely simulating a real space mission from start to finish.

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